Building a Telescope 2 km Underground

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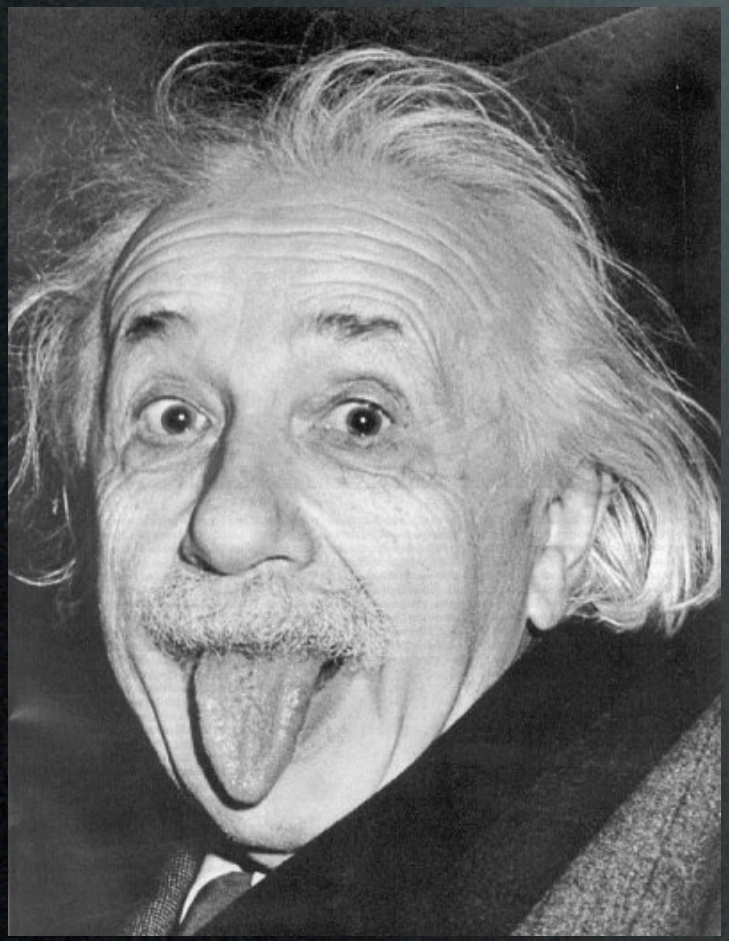
Physics



- We are physicists, we study the properties of energy, matter, space and time.
- Albert Einstein was a famous theoretical physicist. Theoretical physicists try to explain physical phenomena with mathematical models.

$$E = mc^2$$

Physicists?

- But we are experimental physicists. We build experiments and try to test the predictions made by the theoretical models.
- Ernest O. Lawrence was a famous experimental physicist. Lawrence Berkeley National Lab and Lawrence Hall of Science were named after him.

“Light”

- What is the similarity between optical light (which your eyes are sensitive to), radio-wave (FM radio), and X-ray?
- They are all “particles of light” (photons). The only difference between them is their energy. Our eyes are sensitive to photons of relatively low in energy.

Telescopes

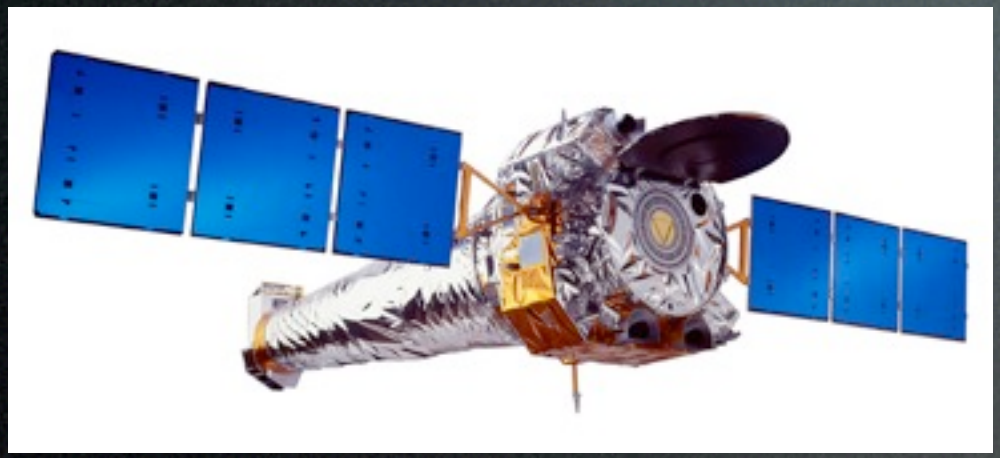
Chabot Space Center, Oakland

- Instruments that allow you to observe distant stellar objects
- The most familiar ones are optical telescopes.
- They are usually ground-based, and are usually located at mountain tops.

Telescopes

- There are telescopes that observe photons in different energy regimes

Space-based



Chandra (X-ray)

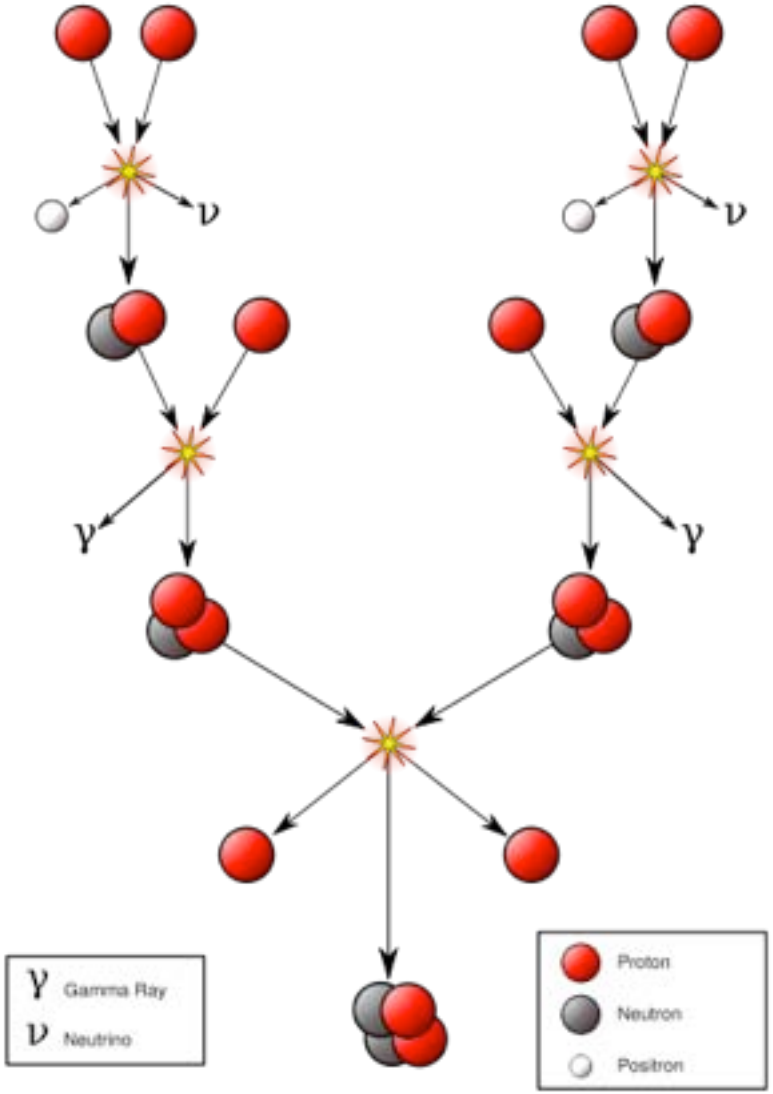
Ground-based

Very Large Array, NM (Radio)

Telescopes

- But telescopes do not necessarily detect photons.
- Photons are not good probes to the inner workings of stellar objects.
- Why not?

Our Sun



- Our Sun is a star. Stars generate energy by nuclear fusion, in which protons are fused to form Helium nuclei (2 protons and 2 neutrons) through a sequence of nuclear reactions in the core.
- Photons from these processes take tens of thousands of years to travel from the solar core to the surface.
- Once the photons have reached the solar surface, they take a further 8 minutes to reach us on Earth.

Our Sun

- So the sunlight we see is at least 10000 years old!
- So how do we know the Sun generates its energy through nuclear fusion in its core?
- Neutrinos!

Neutrinos

- Neutrinos are byproducts of the nuclear fusion process.
- Unlike photons, neutrinos do not interact with matter very much. Neutrinos take almost no time to travel from the solar core to the surface.
- Like photons, neutrinos are fundamental particles in nature.

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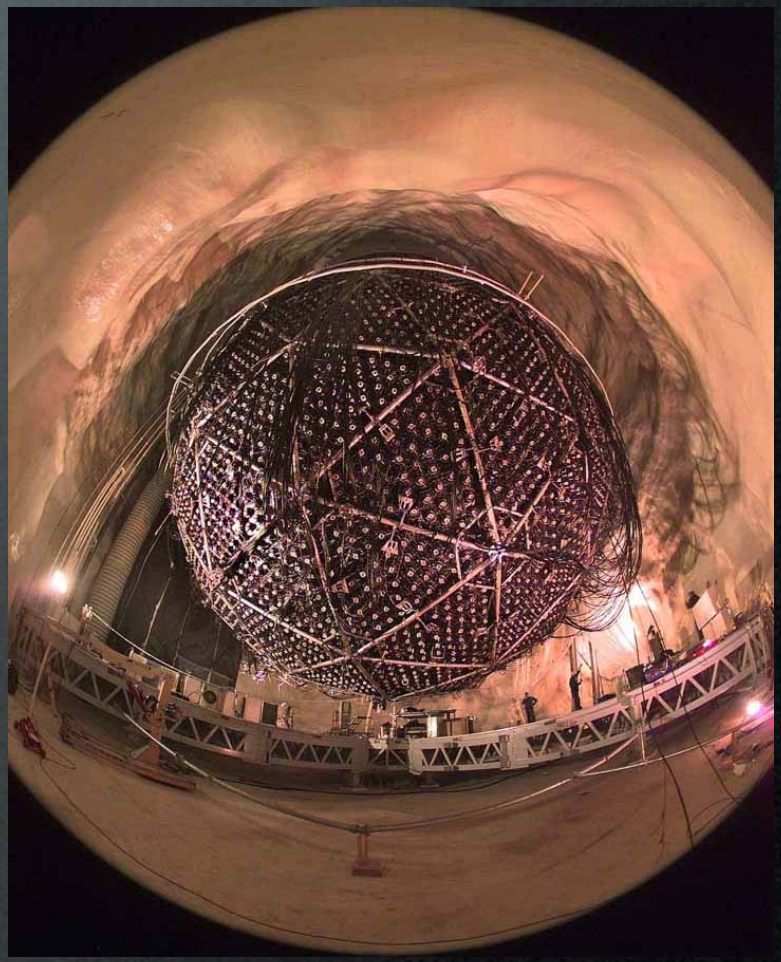
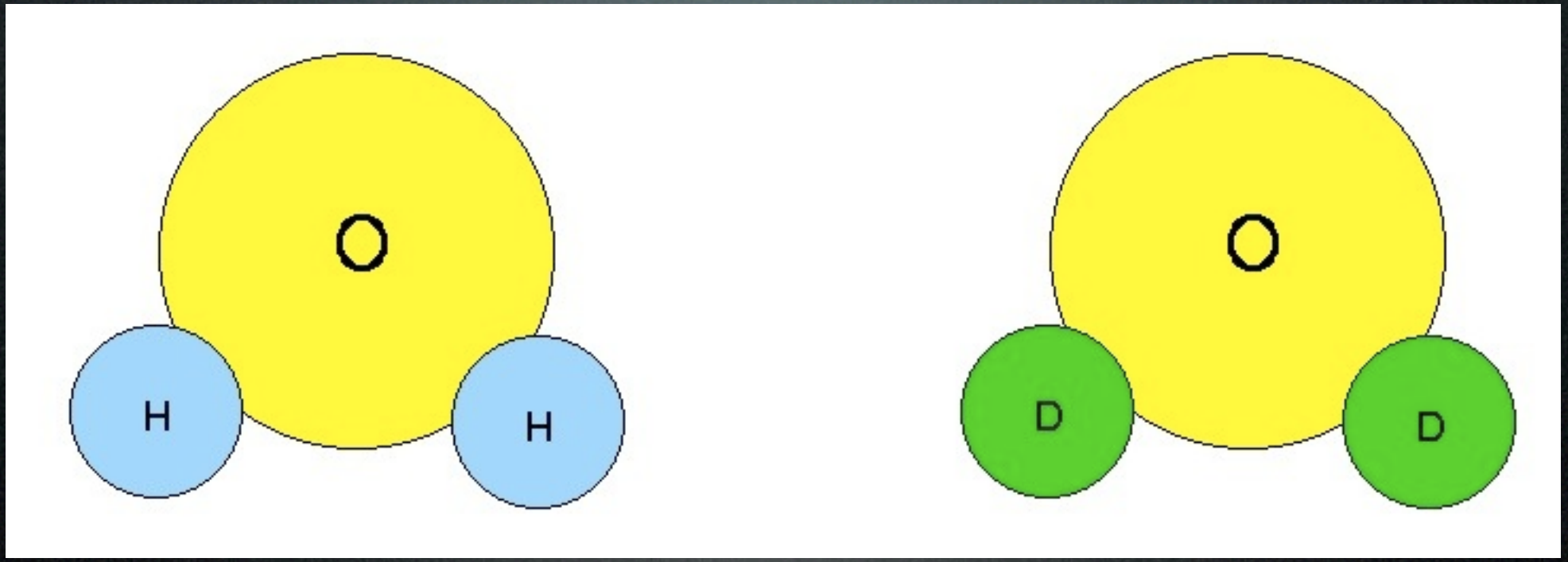
How do you detect neutrinos?

Sudbury Neutrino Observatory (SNO)

- SNO is a neutrino telescope
- It is located in a Canadian mine more than a mile underground.
- Neutrinos interact with the heavy water inside SNO, and create flashes of light.
- This telescope has about 10000 light sensors to detect these flashes.



Water vs Heavy Water



Water

H: hydrogen (1 proton)

Heavy Water

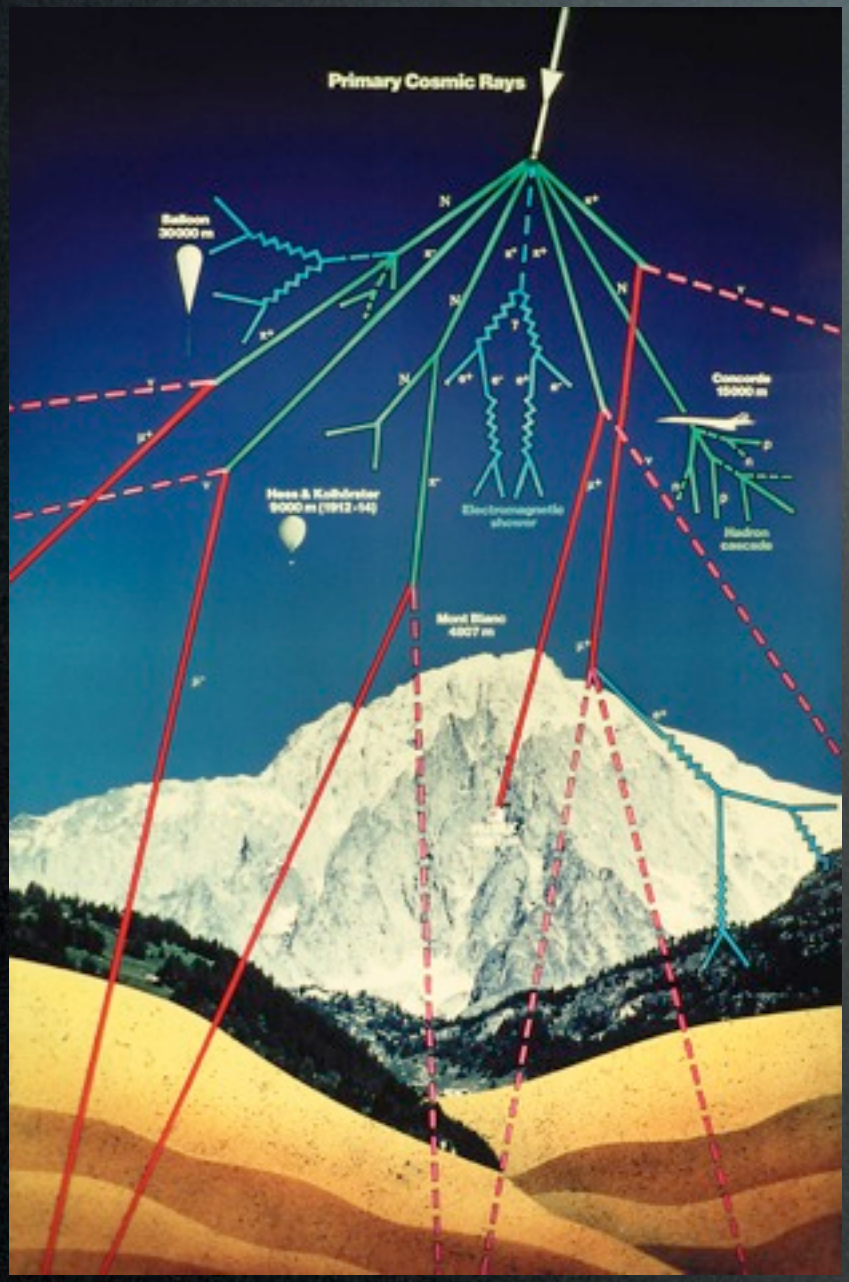
D: deuterium
(1 proton + 1 neutron)

Deuterium is good at stopping neutrinos

Why did you build a telescope underground?

- Neutrinos are can go through almost everything. SNO catches only a few neutrinos from the Sun every day.
- But there are cosmic rays from space. The Earth can stop cosmic rays, but not neutrinos. We can find the neutrinos more easily if the telescope is deep underground.

What are cosmic rays?



- High energy particles (mostly protons) from our solar system or other galactic and extra-galactic sources bombard our Earth's upper atmosphere.
- They interact with nuclei in the atmosphere (nitrogen, oxygen…) and create a shower of other particles.
- A significant fraction of these secondary particles are muons, a heavier cousin of electrons.
- You will make measurements of these muons later.

Can you find Alan?

No, there are too many people!

Can you find Alan?

Maybe, if you look very carefully.

Can you find Alan?

Yes, because there are fewer people in the picture. If there are fewer cosmic rays, it is easier to find neutrinos too.

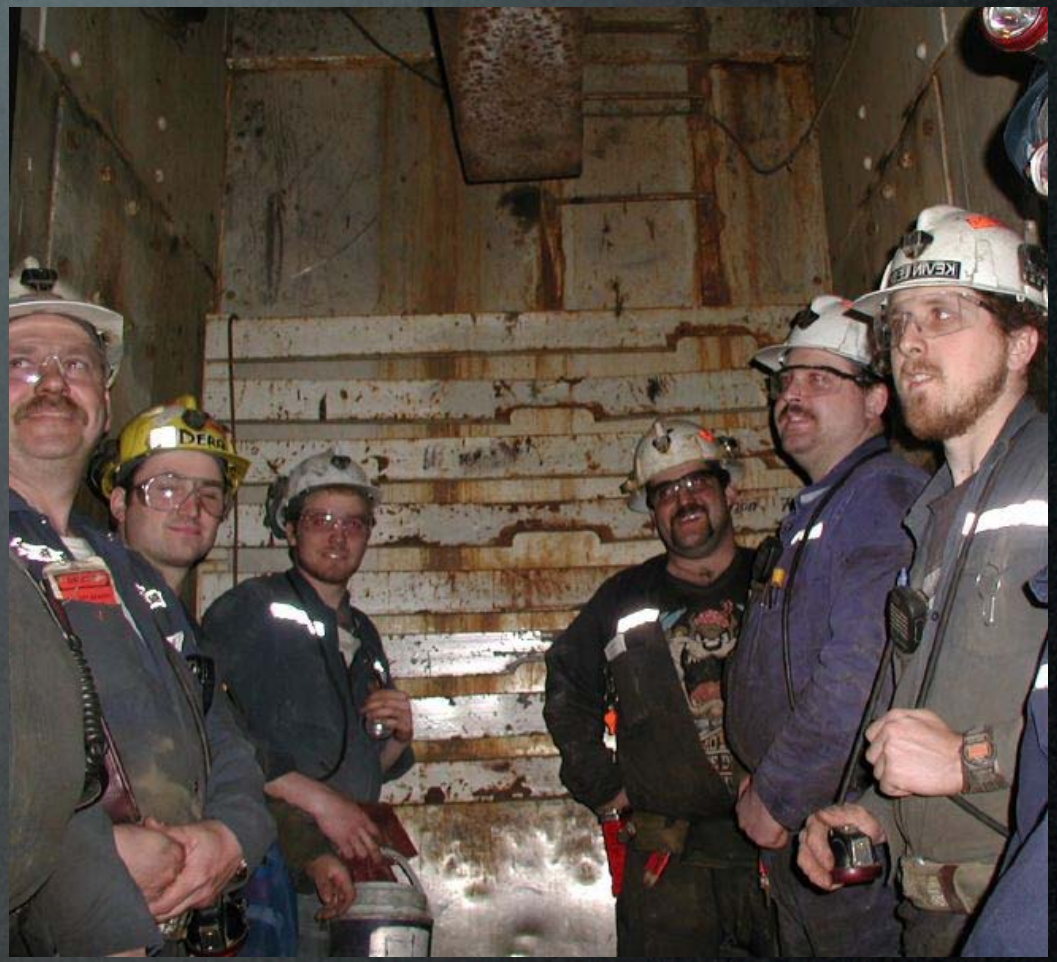
SNO

- SNO is located in Sudbury, Canada.
- It is a joint project between Canada, US and the UK.
- The heavy water (worth about $300 Million) was on loan from the Canadian government.

A SNO Tour

This is the entrance to the mine.

A SNO Tour



We take the elevator (aka cage) down to the mine.

A SNO Tour

After we get off the elevator, we walk a mile to our laboratory.

A SNO Tour

The blue door is the entrance to the laboratory.

A SNO Tour

Then we take off our miner clothing and shower. We have to be very clean when we work on SNO. The lab is a cleanroom

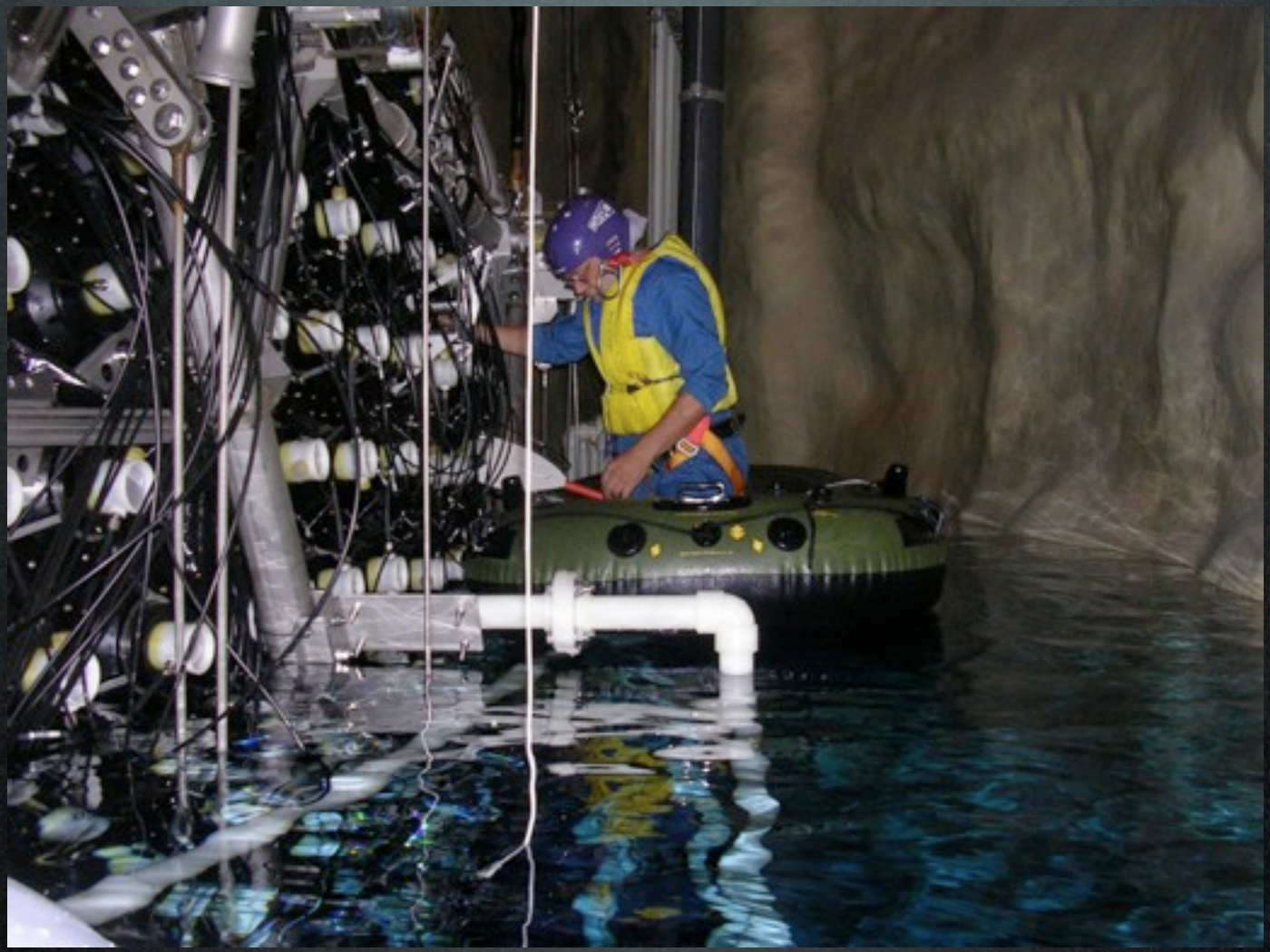
A SNO Tour

This is the lunch room where we take a break after the shower!

A SNO Tour

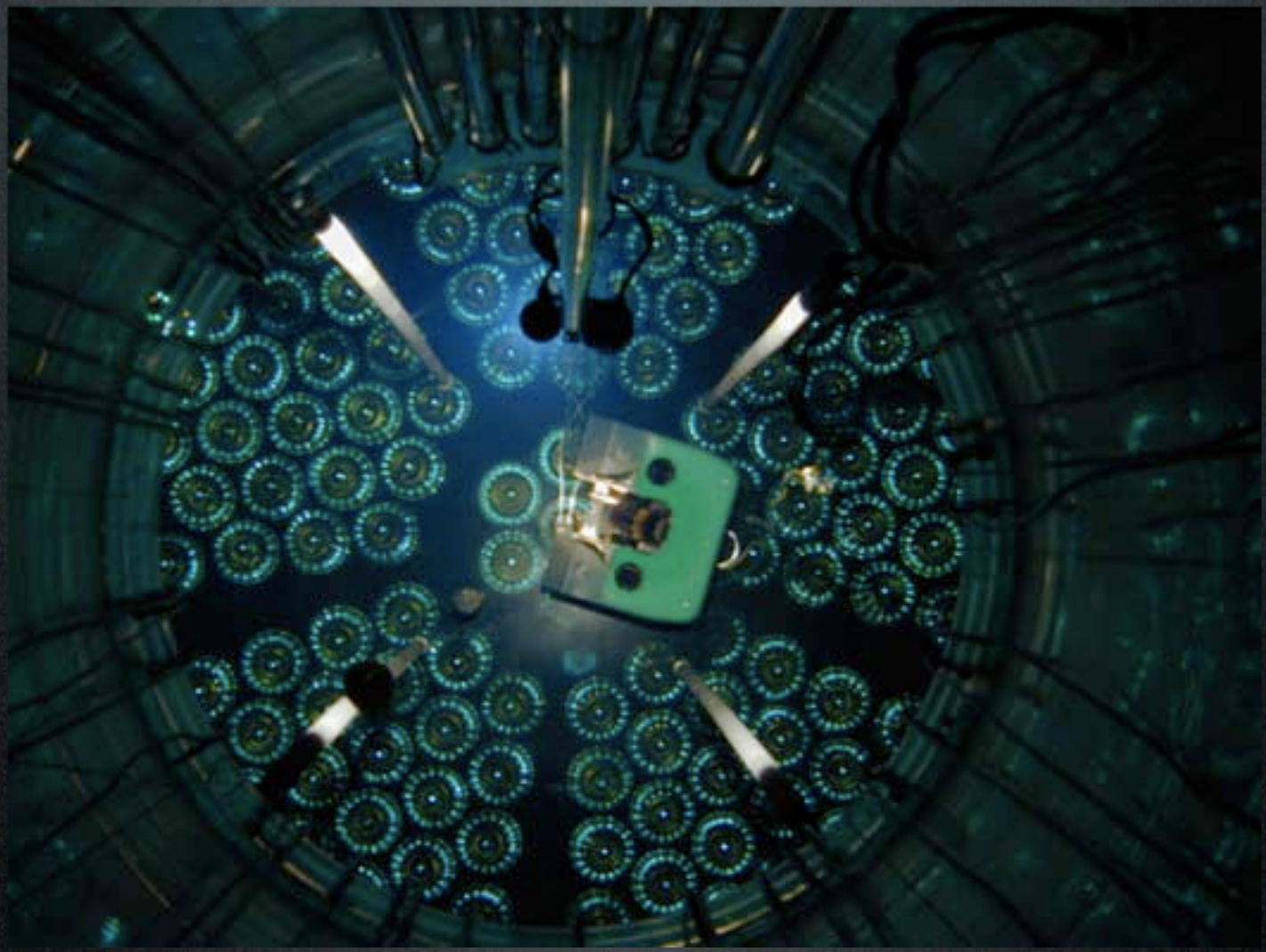
This is the water system that circulates and purifies the heavy water

A SNO Tour



We have to check on SNO sometimes.
We use a rubber boat.

A SNO Tour



We sent a submarine into SNO to install certain components.

A SNO Tour

Young students pilot the submarine because they are good at video games.

A SNO Tour

At the end of the day, we walk back to the elevator.
It takes us back to surface.

What did we found?

- SNO observed neutrinos from the Sun.
- SNO results show that computer models of the Sun predict the correct total number of neutrinos from the fusion process.
- Theoretical physicists thought neutrinos had zero mass (like photons). SNO proved them wrong.

SNO

- Show event display here

Muon Measurement

- To determine how the muon flux (# of muons per unit area) depends on the zenith angle
- Adjust H
- Count for 3 min. at each H
- Plot the results

- How would you explain the results?